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Demonstration of Jackhammer Incorporating Depleted Uranium

L.E. Fischer, R.W. Hoard, D. L. Carter, M.D. Saculla, G.V. Wilson

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Larry E. Fischer, Ronald W. Hoard, David L. Carter, Michael D. Saculla, Geoffrey V. Wilson*

*Summer Student, 1998/1999

CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

1.1 Background

The United States Government currently has an abundance of depleted uranium (DU). This surplus of about 1 billion pounds is the result of an enrichment process using gaseous diffusion to produce enriched and depleted uranium. The enriched uranium has been used primarily for either nuclear weapons for the military or nuclear fuel for the commercial power industry. Most of the depleted uranium remains at the enrichment process plants in the form of depleted uranium hexafluoride (DUF_6). The Department of Energy (DOE) recently began a study to identify possible commercial applications for the surplus material.

One of these potential applications is to use the DU in high-density strikers/hammers in pneumatically driven tools, such as jack hammers and piledrivers to improve their impulse performance. The use of DU could potentially increase tunneling velocity and excavation into target materials with improved efficiency.

This report describes the efforts undertaken to analyze the particulars of using DU in two specific striking applications: the jackhammer and chipper tool.

2.0 SCOPE AND APPROACH

Industry uses many types of impact tools and equipment ranging from small chippers and scalers to medium jackhammers, large pile-drivers, and stamping machines. The effectiveness of an impact tool partially depends on the density of the part that provides the impact energy. The jackhammer and chipper were used to demonstrate increased effectiveness with the increase of material density. A commercially available jackhammer and chipper were modified by replacing their steel pistons with a heavy metal tungsten alloy which has essentially the same density as DU. Although tungsten alloy is much more expensive than DU, it is not radioactive and hence is easier to fabricate and to test. The jackhammer design modifications took into account that DU is radioactive.

A test demonstration was conducted to compare the modified jackhammer and chipper with the original unmodified ones. Test parameters included cutting speed or depth, thickness and hardness of material being cut, and type of cutting tools. Specific effects and overall comfort of the operator were assessed.

3.0 MECHANICS OF EQUIPMENT

3.1 Jackhammer

A jackhammer is a portable oscillating rock drill operated by compressed air. The compressed air provides a pressure behind a piston/striker bar (PSB) and imparts kinetic energy to the PSB. The PSB strikes a tool bit providing it with momentum and energy. The tool bit impacts and penetrates a target material such as concrete. The penetration into the target material depends on the momentum and energy transferred to the target material.

3.2 Chipper

The chipper works on the same principle as the jackhammer in that it uses compressed air to accelerate a piston, which impacts a tool bit which then impacts the target material. The primary difference from the jackhammer is that the chipper is a smaller hand held tool and is used for knocking out bolts or chipping into concrete.

4.0 MODIFIED DESIGN AND ANALYSIS

4.1 Jackhammer

A cutaway illustration of a jackhammer is shown in Figure 1. This specific jackhammer model has an integral PSB which imparts the kinetic energy to the bit or other impacted tool. The initial DU design modifies only the integral PSB. The striker bar portion is bored out, leaving some cladding material in order to completely encapsulate the DU. The initial design used a press fit cap to hold the tungsten alloy bar (substitute for DU) in place inside the bored out cavity. The initial design modification increased the piston/striker bar weight by 60%. Buckling and finite element analysis of the bored out bar with the tungsten alloy insert were performed. The analyses showed that the design would not fail for the anticipated loading. During testing, the jackhammer vibration caused the press fit cap assembly to disengage due to knock-on by the tungsten alloy bar against the end of the cavity. The cladding material failed and the testing ended before any significant data was recorded.

A second design was developed that used a cap screw to hold the tungsten alloy bar in place against the end of the cavity. In its final configuration, shown in Figure 2, the cap screw was epoxied in place with a 200 ft-lb torque to resist vibration forces to loosen it. This design configuration increases the weight by 45% compared to the unmodified design. A production model design would use an electroless nickel-coated DU bar inside the cavity and would weigh 40–60% heavier than the unmodified design (References 1-2). If the entire piston/striker bar part were entirely made of DU, the weight increase would be over 140%.

Several analytical models have been developed that describe the motion of the PSB of a pneumatic jackhammer and the forces exerted by the end of the bit during penetration of a target (References 3-8). These models are somewhat complex and in some cases are programmed to execute on a computer. To estimate the effect of using a heavy metal in place of steel in the PSB a simplified two component vibration model was used based on the analytical model presented in reference 8.

The initial penetration rate V_b of the bit is estimated by

$$V_b = \frac{1}{\rho_b c_b A_b}(F_b - F_r) \tag{1}$$

Where ρ, c, A, are the density, wave velocity and area of the bit denoted by the subscript b. The bit forward force is Fb and the reflected force is Fr. If the target force penetration efficiency is 50%, expression (1) becomes

$$V_r = 1.5V_o\left[\frac{\rho_p c_p A_p}{\rho_p c_p A_p + \rho_b c_b A_b}\right] \tag{2}$$

Where Vo is the initial impact velocity of the PSB onto the bit and ρ, c A are the density, wave velocity and area of the PSB and bit denoted by subscripts p and b respectively.

The ratio (Vr) of the bit velocity for the modified PSB to that of original steel PSB can be estimated by

$$V_r = \frac{V_b^1}{V_b} = \frac{A_b/A_p}{1 + \dfrac{\rho_b c_b A_b}{\rho_p^1 c_p^1}} = \frac{\dfrac{A_p}{A_b} + 1}{\dfrac{A_p}{A_b} + \sqrt{\dfrac{\rho_p^1 E_p^1}{\rho_b E_b}}} \tag{3}$$

In Figure 3 the initial bit velocity ratio is presented as a function of the density, young modulus (ρE) ratios normalized steel materials for specific bit to PBS area ratios.

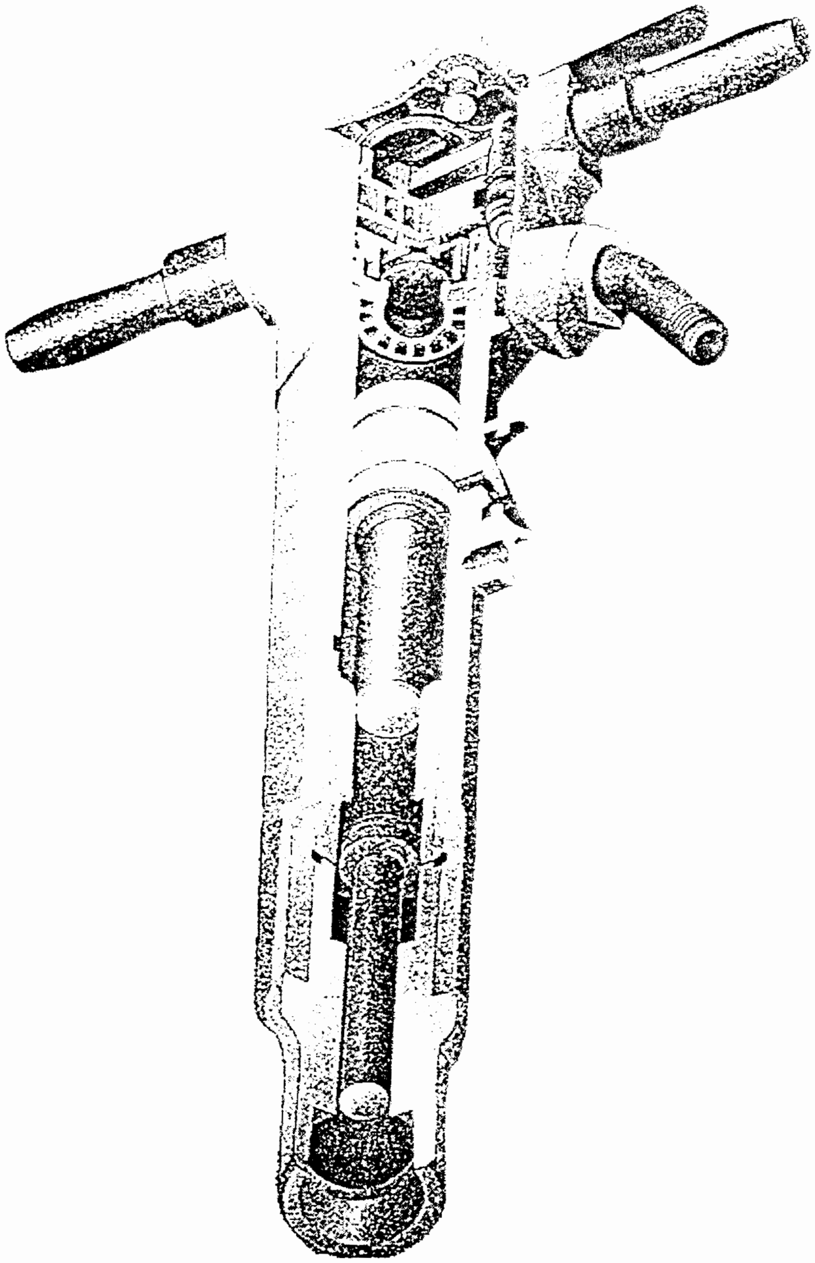

Figure 1 Cutaway of typical jackhammer

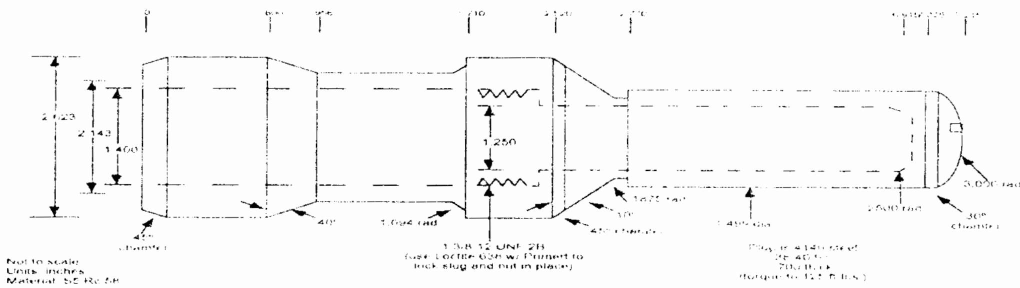

Figure 2 Modified piston/striker bar design

$$V(A_r, \rho E_r) := \frac{A_r + 1}{A_r + \sqrt{\frac{1}{\rho E_r}}} \qquad \text{note that:} \qquad A_r = \frac{A_P}{A_B} \qquad \rho E_r = \frac{\rho_B \cdot E_B}{\rho_P \cdot E_P}$$

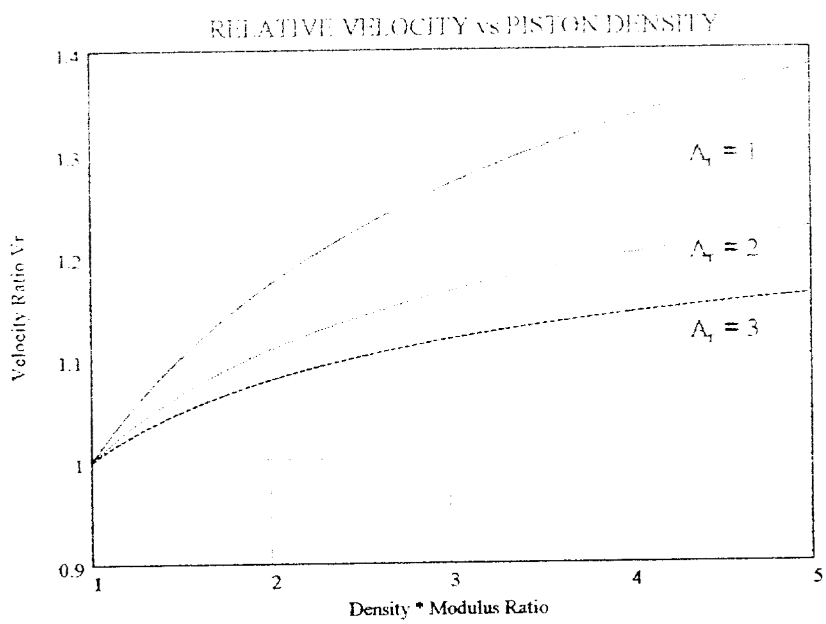

Figure 3 Velocity ratio as function of product of density and Young's modulus ratio normalized to steel piston/striker and steel bit

4.2 Chipper

The chipper tool was selected to gain experience in operating a lightweight pneumatic impact tool. A model similar to the one in Figure 4 was tested. This particular model uses a beehive or spring retainer to keep the chisel within the tool. The air-driven chipper drives a cylindrical steel piston against a chisel, which impacts the target material. The chipper was modified by replacing the steel piston with a tungsten alloy one. A sketch of the piston is shown in Figure 5.

Originally we planned only to test the chipper tool penetration rate or depth into various materials for the two configurations. In operating the chipper tool it was observed that the beehive or spring retainer extended further with the tungsten alloy piston compared to the steel one. There was also a stronger kick or force with the tungsten alloy piston. We decided to measure the spring deflection and spring force to compare the modified tool with the unmodified tool in addition to the penetration tests.

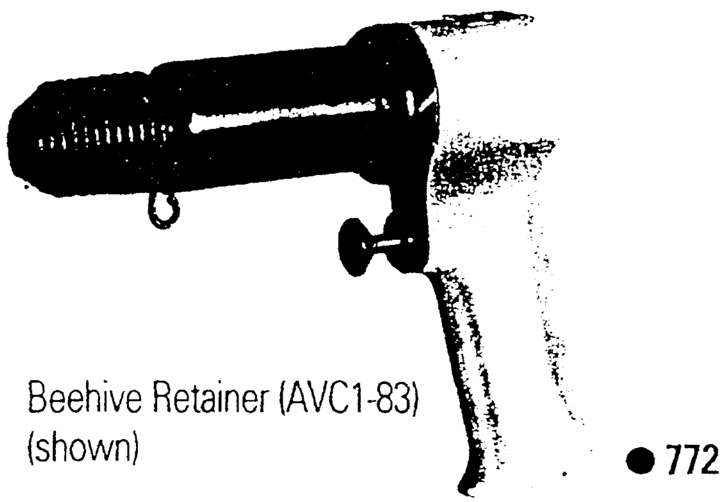

Figure 4 Chipper tool

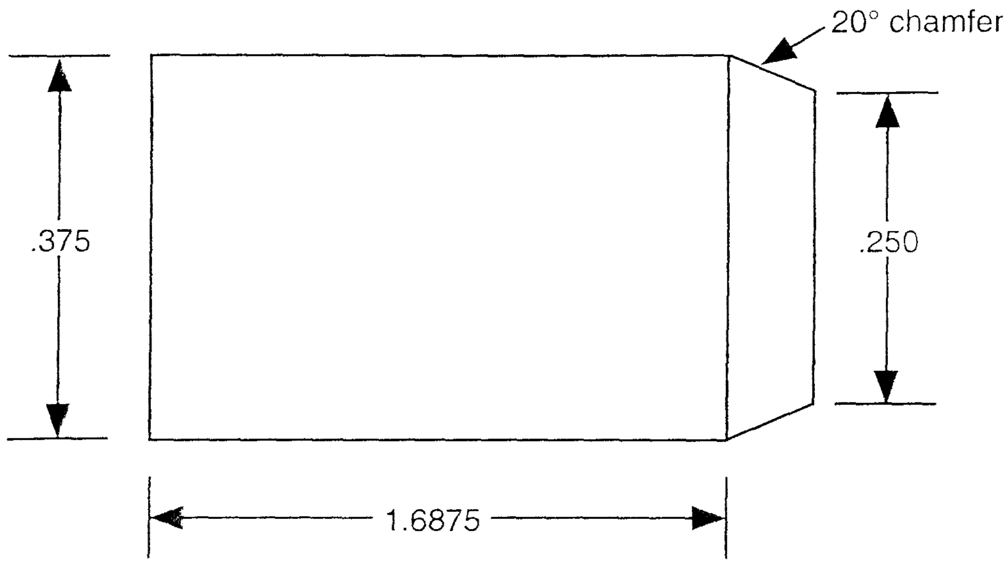

Figure 5 Chipper piston

5.0 TESTS

5.1 Chipper

The approach for comparing tunneling velocity was to measure the hole depth made by the chipper in an oak wood block using, in one trial, the steel piston, and in another trial, the tungsten alloy piston for the same length of time. The procedure was to apply the chipper chisel against the oak piece, and activate the chipper for a set time period. The depth of the hole was then measured by a micrometer. The same test was then performed on aluminum alloy plate.

The test data are summarized in Tables 1 and 2 for two test sequences.. From the data is appears that the tunneling velocity in the oak is higher for the tungsten alloy piston, but not necessarily higher in the aluminum. The data show large variations for the same test time periods. These variations were initially thought to be due to the variation in wood hardness and plastic hardness of the aluminum. As the tests continued it became apparent that the tunneling velocity was very dependent on the force applied on the chipper tool to hold it against the target material. One operator was able to apply enough force to stall the chipper tool with the steel piston, but could not stall the chipper tool with the tungsten alloy piston. After additional testing and observations it was concluded that the chipper tool with the tungsten alloy piston had a strong force or a "kick" to it, and the retainer spring extended further during operation. It was also concluded that the test penetration results are uncertain.

Table 1 Chipper Tool Penetration Test #1

Oak Wood Target Depth (in)			
Time (sec)	**Steel**	**Tungsten alloy**	**Percent difference**
20	0.313	0.891	180
Aluminum 1060 Bar Depth (in)			
Time (sec)	**Steel**	**Tungsten alloy**	**Percent difference**
30	0.012	0.026	116
45	0.025	0.039	56
60	0.029	0.039	34
75	0.034	0.039	15

Table 2 Chipper Tool Penetration Test #2

Oak Wood Target Depth (in)			
Time (sec)	**Steel**	**Tungsten alloy**	**Percent difference**
10	0.29	0.298	2.7
20	0.604	0.778	29
Aluminum 1060 Bar Depth (in)			
Time (sec)	**Steel**	**Tungsten alloy**	**Percent difference**
15	0.029	0.019	-35
30	0.025	0.032	28
45	0.036	0.023	-37
60	0.03	0.04	33

It was decided to measure the spring displacement during operation and the spring displacement/force characteristics to estimate the force transferred to the bit from the piston. The chipper was mounted in a vise to reduce recoil effects. A calibration grid was placed behind the chipper to measure the spring displacement. A video recorder was used to measure the spring displacement at the rate of one frame per millisecond. Each run lasted several seconds to reduce startup effects. Three tests were performed with the tungsten alloy piston and two with the steel piston. The spring extension versus time for one cycle is shown in Figure 6. The peak extension of the spring was greater for the tungsten alloy piston. The spring displacement/force characteristics were measured and the peak force was calculated for teach of the test runs. The measured peak displacements and calculated forces are summarized in Table 3.

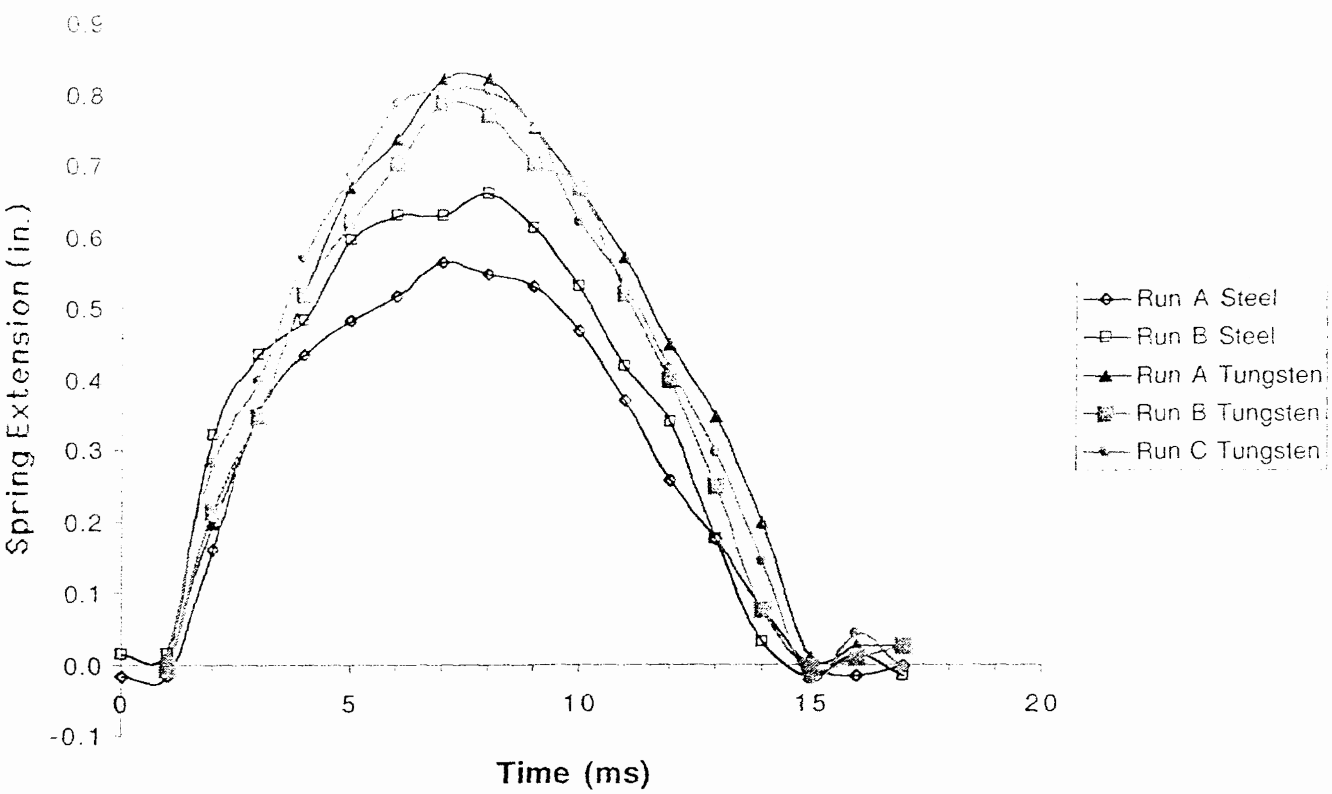

Figure 6 Spring extension versus time for chipper tool

The average measured peak displacements for the spring are 0.81 and 0.66 inches for the tungsten alloy and steel pistons, respectively. The corresponding average peak forces are 42.4 g and 35.6 g. From the spring force displacement curve it is concluded that the impact energy of the bit is significantly higher for the tungsten alloy piston.

The bit velocity versus time was calculated from the spring displacement data and is presented in Table 4. In general the bit velocity for the tungsten alloy piston was higher then that for the steel. The initial velocity was 6% higher and the rebound impact velocity was 51% higher. The momentum of the tungsten alloy piston is significantly higher.

Table 3 Chipper Tool Displacement/Force Tests

	Tungsten alloy		Steel	
Run number	Displacement peak	Calculated force (lbf)[1]	Displacement (in)	Calculated force (lbf)[1]
1	0.810	42.4	0.621	34.0
2	0.793	41.6	0.690	37.1
3	0.828	43.2		
Average	**0.810**	**42.4**	**0.656**	**35.6**
Standard deviation	0.018	0.80	0.049	2.19
Coeff. of verification	2.2%	1.9%	7.4	6.2%

Table 4 Bit Velocity versus Time for Chipper Tools

	Velocity	
Time	Steel	Tungsten alloy
(msec)	(in/sec)	(in/sec)
1	197	209
2	156	185
3	116	155
4	78	119
5	41	79
6	7	38
7	-23	-3
8	-49	-42
9	-71	-77
10	-87	-107
11	-98	-129
12	-102	-142
13	-98	-143
14	-87	-132

[1] Force (lbf) = 6.52 + [44.28 x spring displacement (in)]

5.2 Jackhammer

The jackhammer tests were conducted using large slabs of concrete that had been excavated from various buildings at the LLNL site. The first tests using the initially modified design abruptly ended when the piston cladding failed. Insufficient data was collected to make any quantitative conclusions on the performance but prior to the failure the jackhammer with the tungsten alloy piston appeared to cut faster into the concrete slab. The cladding failure was attributed to knock-on between the tungsten alloy insert and the end of the hollow cylindrical cladding after the press fit became loose.

The second design was fabricated and used a cap screw in the place of the press fit plug. The cap screw was torqued to approximately 60 ft-lbs to lock it into place. The testing went smoothly until the cap screw loosened with the vibration and the cladding failed due to knock-on. A third piston was fabricated which had the cap screw torqued to 200 ft-lbs and epoxied in place. This final design did not fail and was used to cut up a large concrete slab to demonstrate its durability.

The concrete slabs were approximately 9 feet square and 6 inches thick. The test procedure was to record the time it took for the jackhammer to cut through the 6-inch section. The results of the tests are summarized in Table 5 for the steel and tungsten alloy pistons. The average cutting time for the steel piston was 11.3 second, whereas the time for the tungsten alloy piston was 8.0 seconds. On average, the cutting time for the tungsten alloy piston was approximately 41% faster than the steel piston. More test data would have been taken but the last slab had some cracking due to handling and had some steel reinforcement inside, which limited the locations where valid testing could occur. However, the jackhammer with the tungsten alloy piston was then used to break up the useable sections to demonstrate durability.

Table 5 Jackhammer Tests

Steel piston cutting time (sec)	Tungsten alloy piston cutting time (sec)
10.0	8.1
11.0	9.1
12.0	8.5
11.7	8.1
11.8	8.2
11.2	
Average = 11.3	**Average = 8.4**

6.0 TEST AND ANALYSIS COMPARISON

Both theory and preliminary experiment suggest that by increasing the density of the piston part on either impact system, the penetration rate is increased, which is the main objective of the tool.

The area ratio of the chipper piston to the bit is 1.5. The density modulus ratio is 4.0. Using Figure 3.0 the relative velocity ratio of the bit was calculated to be 1.25 for the chipper tool. The measured velocity ratio for the bit with the tungsten piston working against the retainer spring is on the average 34% higher. The measured penetration rate ratio is inconclusive due to data scatter.

The area ratio of the jackhammer PBS to the bit is 1.0. The equivalent density modules ratio of the tungsten alloy to steel is 2.4. Using Figure 3 the relative velocity ratio of the bit was calculated to be 1.22. The measured average penetration rate is 41% faster for the modified PBS tests.

For both cases, the chipper tool and jackhammer, the measured performance for the modified tools was higher than that calculated for the analytical model. The higher measured result may be attributed to increased target force penetration efficiency for the modified tools, uncertainties in conducting the test, or the need to develop a new three component impact model of the penetration process.

The modified designed piston did not have a significant effect on the handling of the jackhammer as a whole, especially since the extra weight of the piston only adds a few pounds to a 90-pound jackhammer. The operator thought there was no significant difference between the two jackhammers, but he could feel more shock in his hands when using the modified PBS but it was still comfortable. The sound level was also comparable to a regular jackhammer. The modified chipper was only 4db higher than the steel piston design.

7.0 CONCLUSION & RECOMMENDATION

The experimental data suggests that the performance improvement in terms of bit velocity or penetration rate is greater than that predicted by a simplified analytical model. The experimental tests had uncertainties in several areas including local material property variations in the target material and operator pressure variations. The material property variations can be reduced by using a well characterized homogenous grout target material. Operator variations can be eliminated by using a mechanical setup similar to the jackhammer system used in Reference 8. Additional tests should be performed using Du preferably with a nickel coating to control contamination. The best uses or benefits in using DU in impact equipment are most likely in heavy stamping machines or pile drivers because of potential licensing difficulties of radioactive materials.

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